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Fresh and hardened properties of Polypropylene fiber added Self-Consolidating Concrete

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ABSTRACT

Self-Consolidating Concrete (SCC) is a special concrete which is highly flowable, non-segregating and by its own weight spread into place, completely fill the formwork even in the presence of dense reinforcement and then encapsulate the rebar without the need of any additional compaction. Similar with other cement-based materials, SCC also has a brittle characteristic. This research conducted to evaluate the effects of polypropylene fiber addition on fresh state characteristics of SCC mixes, and investigate the effects of polypropylene fiber on some hardened properties of SCC. In this research, concrete mixes were added with polypropylene fiber of 0%, 0.05%, 0.10%, and 0.15% volume fraction. Fresh characteristics were evaluated based on its passing ability, flowability, viscosity, and segregation resistance using J-ring, Slump flow, and Sieve Segregation Resistance tests. After 28 days of curing, compressive, splitting tensile strength, and drop-weight impact resistance were tested. Tests results indicate that polypropylene fibers tend to reduce the flowability and passing ability but will increase viscosity and segregation resistance of SCC. Furthermore, it can be concluded that polypropylene fiber reduce deformability of SCC in the fresh state. After 28 days of curing, concrete specimens' tests indicate that polypropylene fiber addition up to 0.10% of volume fraction tend to improve the compressive strength, tensile strength, and impact resistance of hardened SCC. It also can be suggested that polypropylene fibers allowed to be added into SCC mixes up to 0.10% by volume of concrete.

Keywords: Self-Consolidating Concrete, Polypropylene fiber, Fresh characteristics, Hardened properties.

1. Introduction

1.1 Background of Study

Self-Consolidating concrete (SCC), also known as self compacting concrete, is a highly flowable, non-segregating concrete and by its own weight spread into place, completely fill the formwork even in the presence of dense reinforcement and then encapsulate the rebar without the need of any additional compaction. Development SCC is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. Due to its high deformability and resistance to segregation, it has the capacity to completely fill the formwork, easy to flow in complex forms with congested reinforcement and encapsulate the reinforcement without any influence of the workers skills. This is in contrast to traditional concrete, where the difficulties in compaction could cause entrapped air voids and reduce the strength and durability of concrete. SCC can be defined as an engineered material consisting of cement, aggregates, water, filler, and chemical admixtures to take care of specific requirements, such as, high flowability, passing ability, adequate

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viscosity, and segregation resistance. In the fresh state, this type of concrete should be able to flow, spread and consolidate under its own weight.

SCC must satisfy the following workability performance criteria: 1) Flowability: The ease of flow of fresh concrete when unconfined by formwork and/or reinforcement; 2) Viscosity: The resistance to flow of a material (e.g. SCC) once flow has started; 3) Passing ability: The ability of fresh concrete to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking; and 4) Stability: the ability of SCC to remain homogenous by resisting segregation, bleeding, and air popping during transport, placement, and after placement.

Due to its characteristics, SCC provides several benefits, such as: greater freedom in shape design, easier pumping and placing, improved consolidation around reinforcement, higher bond strength with reinforcement, uniform and complete consolidation, better surface finishes, improved durability, reduced noise levels caused by absence of vibration, labor savings, faster construction and also more spacious and safe working environment. Those characteristics of SCC can be achieved by implementing following basic principles in the mix design process; 1) lower coarse aggregate content, 2) increasing paste content, 3) lower water/powder ratio, (powder is defined as cement added with filler, such as: fly ash, silica fume, etc.), and 4) the use of superplasticizer.

Considering lower water-cement ratio and higher content of cementitious materials compared to conventional concrete, SCC should have improved durability and strength. However, similar with other types of cement-based materials, SCC also has a brittle characteristic. This characteristic can be improved by adding fibers in to the concrete mix. The term fiber added concrete can be defined as concrete containing dispersed randomly oriented fibers. Inherently concrete is brittle under tensile loading and mechanical properties of concrete may be improved by randomly oriented discrete fibers which prevent or control initiation, propagation, or coalescence of cracks. Fiber added concrete properties and performance change, depending on the properties of concrete and the fibers. The properties of fibers that are usually of interest are fiber concentration, fiber geometry, fiber orientation, and fiber distribution. Moreover, using a single type of fiber may improve the properties of fiber added concrete to a limited level. Shortcut type of fiber can be added to bridge microcracks of which growth can be controlled. This leads to a higher tensile strength of the composite.

Unlike its effects to hardened concrete, the presence of fibers in concrete mixes can cause significant deterioration to the concrete workability. On the other hand, workability is very important for SCC to achieve its requirement to flow, pass through tight openings without blocking, and completely consolidate by its own weight. Based on those reasons, this research was designed to investigate effects of polypropylene fiber addition on some fresh and mechanical properties of SCC.

1.2 Objectives

This research conducted to investigate effect of polypropylene fiber addition on four main characteristics of SCC in the fresh state: flowability, viscosity, passing ability and segregation resistance. Effect of polypropylene fiber addition on compressive strength, splitting tensile strength, and impact resistance of SCC also wanted to be known. Based on the results of fresh and hardened SCC tests, prediction of optimum volume fraction of polypropylene fiber in SCC mixes can be determined.

2. Experimental Work

2.1 Materials and Mix Proportion

Polypropylene was chosen, because it is not expensive, inert in high pH cementitious environment and easy to disperse. In this research, monofilament polypropylene with 18 µm diameter, and 12 mm length, which having 0.91 g/cm3 density were used. The mixtures investigated in this study were prepared with Ordinary Portland Cement which is fulfilled the requirements in the Indonesian Standard SNI 15-2049-2004.

Well graded crushed granite, with Saturated Surface Dry (SSD) density of 2.48, was used as coarse aggregate. A maximum aggregate size of 20 mm was chosen for coarse aggregates, as it is commonly used for SCC mixes. Coarse aggregates were washed to remove fine sandy particles that can hinder rheological properties. Well-graded natural sand, with SSD density of 2.65, and maximum size 5 mm, was used as the fine aggregate. Silica fume used as mineral admixture while polycarboxylate based superplastisticizer also added in to the mixes. Concrete mixes were prepared containing 0%, 0.05%, 0.10%, and 0.15% of polypropylene fibers (measured by fibers volume in concrete volume). Detail of mixes proportion for this research can be observed in following Table 1.

Table 1: Mix Proportion

Material	Volume Fraction of Polypropylene Fibers			
	0.0%	0.05%	0.1%	0.15%
Polypropylene fibers (kg/m^3)	0.00	0.45	0.90	1.35
Water (lt/m^3)	212.00	212.00	212.00	212.00
Portland Cement (kg/m^3)	435.00	435.00	435.00	435.00
Silica fume (kg/m^3)	48.00	48.00	48.00	48.00
Coarse Aggregate (kg/m^3)	648.00	648.00	648.00	648.00
Sand (kg/m^3)	926.00	926.00	926.00	926.00
Superplasticizer (lt/m^3)	4.80	4.80	4.80	4.80

2.2 Details of Experimental Tests

Fresh characteristics of SCC were evaluated based on its four main measurements; passing ability, flowability, viscosity, and segregation resistance. Those characteristics were measured using following instruments; J-ring Test (ASTM C1621), Slump flow, and Sieve Segregation Resistance tests (EFNARC, 2005).

For the investigation of hardened concrete properties, the compressive, splitting tensile strength, and impact resistance of SCC were investigated. Concrete specimens were cured with water immersion for 28 days at the ambient temperature. Compressive strength tests for all the variants of concrete mixes with different fiber contents were done on three cylinders of 150 mm in diameter and 300 mm length, based on ASTM C-39. The compressive strength of concrete was determined as the average of those three specimens for each variant. For tensile strength investigation, the Brazilian splitting tensile test was carried out on three cylinders with 150 mm diameter and a height of 300 mm based on ASTM C496, and the tensile strength of concrete was taken as the average of the those three cylinders for each variant.

Drop-weight test was conducted using ACI 544 Committee recommendations to determine the impact resistance of concrete specimens. Each type of the freshly mixed concrete was cast into cylinder molds to make 15x30 cm cylindrical specimens. At the end of 24 hours after casting, the cylindrical specimens were demoulded and immersed in tap water for 28 days. Then, each cylindrical specimen was sawed into four 15x30 cm cylindrical disks for the drop-weight test. In the test, a cylindrical disc was set on a base plate within four positioning lugs, and impacted by repeated blows. The blows were introduced through a 4.45 kg hammer falling continually from a 457 mm height onto a 63.5 mm steel ball, which stood at the center of the top surface of the disc. During the blows impacted onto the disc, the number of blows to the first visible crack on the top surface was defined as the first-crack impact resistance, while the number of the blows to generate the 3-lug-touching action of the disc was considered as the failure impact resistance (Song et al., 2005). The impact resistance was taken as the average of those four cylindrical discs for each variant.

3. Results and Discussion

3.1 Fresh Characteristics

Effects of polypropylene fibers addition on the fresh characteristics of Self-Consolidating Concrete need to be measured to evaluate its workability performance criteria. Comparison of the measured flowability, viscosity, passing ability and segregation ratio of the fresh SCC mixes can be observed in the following Table 2.

Table 2: Effects of Polypropylene Fiber Addition on Fresh Characteristics of SCC

Vol. fraction of Polypropylene (%)	Flowability/ Slump flow (mm)	Viscosity/ T_{500} time (sec)	Passing ability/ J-Ring Test (mm)	Segregation Ratio (%)
0.00	748.33	1.03	4.00	4.24
0.05	686.67	1.13	7.00	1.16
0.10	556.67	1.40	7.92	0.82
0.15	428.33	-	10.58	0.76

The addition of polypropylene fiber into SCC mixes tends to lower the flowability (Slump Flow), as shown in Figure 1.

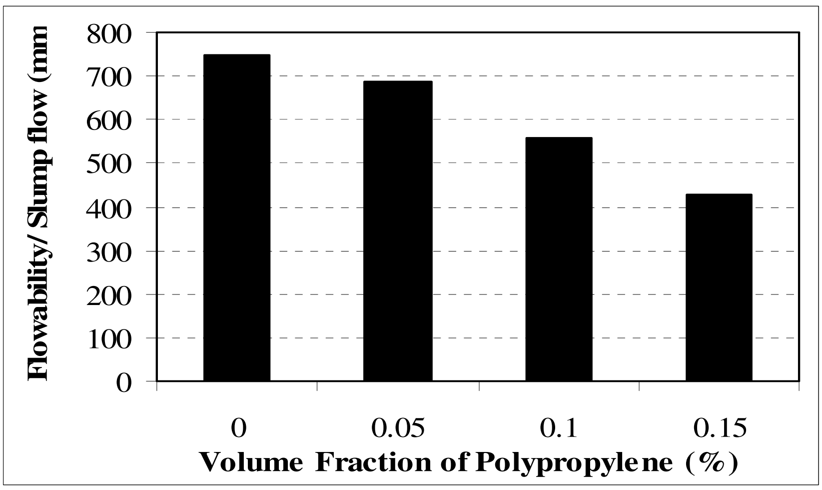

Figure 1: Effect of Polypropylene Fiber Addition on the Flowability of SCC Mixes

When the presence of polypropylene fiber in SCC mixes increased, it can caused lower viscosity of SCC which is indicated by higher measured time of the fresh concrete to flow and reach the 500 mm of diameter, as shown in Figure 2.

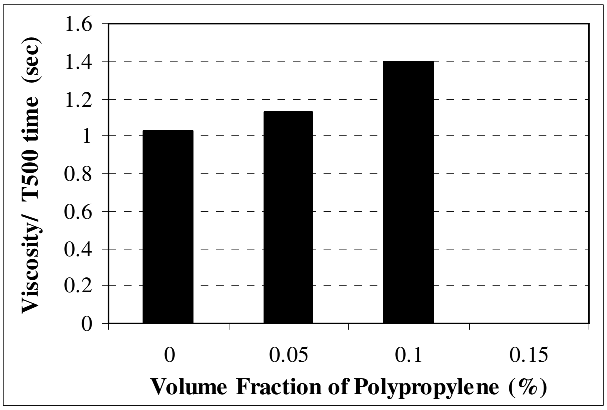

Figure 2: Effect of Polypropylene Fiber Addition on the Viscosity of SCC Mixes

Higher volume fraction of polypropylene fiber addition into SCC mixes will caused lower passing ability of SCC which is measured using J-Ring Test method, as shown in Figure 3.

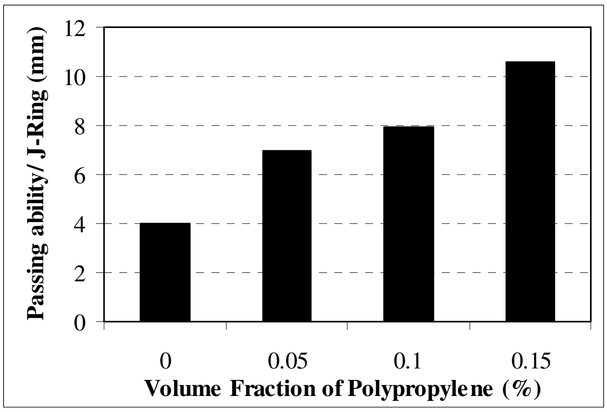

Figure 3: Effect of Polypropylene Fiber Addition on the Passing Ability of SCC Mixes

In the other hand, the segregation ratio of SCC mixes will be lower when the addition of polypropylene fiber into SCC mixes increased, as shown in Figure 4.

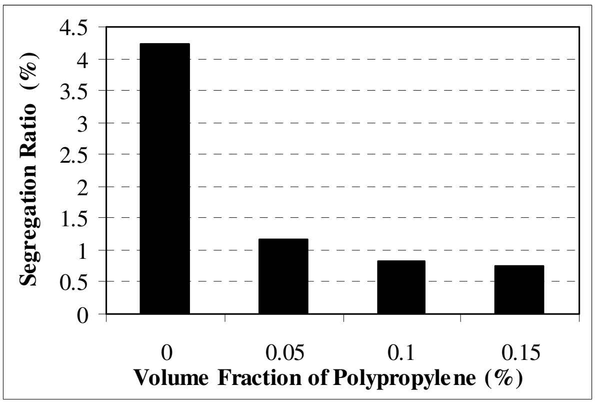

Figure 4: Effect of Polypropylene Fiber Addition on Segregation Ratio of SCC Mixes

3.2 Hardened Properties

In order to evaluate the effects of polypropylene fiber addition on hardened SCC properties, the compressive, splitting tensile strength, and impact resistance of the concrete specimens tested after 28 days of water immersion curing. The following Table 3 shows the results of the tests.

Table 3: Effects of Polypropylene Fiber Addition on Hardened Properties of SCC

Volume fraction of polypropylene fiber (%)	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Impact Resistance (blows)	
			First-crack	Failure
0.00	40.71	4.106	71	76
0.05	42.93	4.264	111	121
0.10	42.78	4.374	196	200
0.15	37.99	3.938	31	35

Effects of polypropylene fiber content on compressive strength of hardened SCC can be observed in Figure 5. The compressive strength tends to increase when the fiber added up to 0.05 percent, and then decrease after 0.10 percent of polypropylene addition.

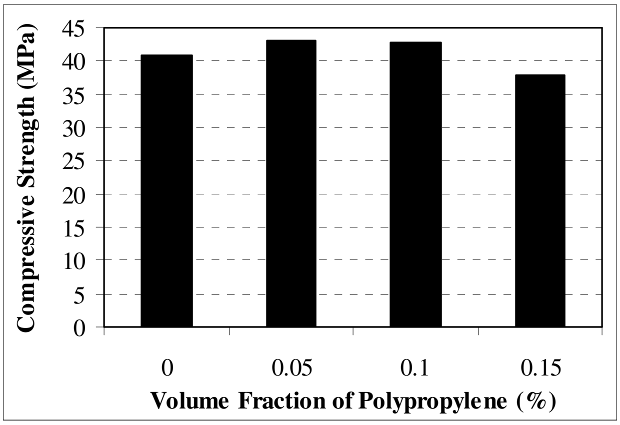

Figure 5: Effect of Polypropylene Fiber Addition on the Compressive Strength of SCC

Better splitting tensile strength can be observed when the fiber added up to 0.10 percent, and then tend to decrease after that. The splitting tensile test result is illustrated in Figure 6.

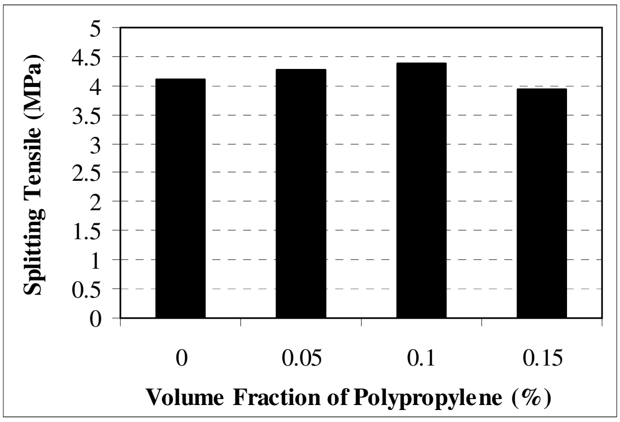

Figure 6: Effect of Polypropylene Fiber Addition on the Splitting Tensile Strength of SCC

Based on the test results, polypropylene fiber additions also provide positive effects on the impact resistance of hardened SCC. The first-crack and failure impact resistance found to be better when the fiber added up to 0.10 percent, and then decrease after 0.15 percent of polypropylene addition. Test results related with the impact resistance of hardened SCC shown in Figure 7.

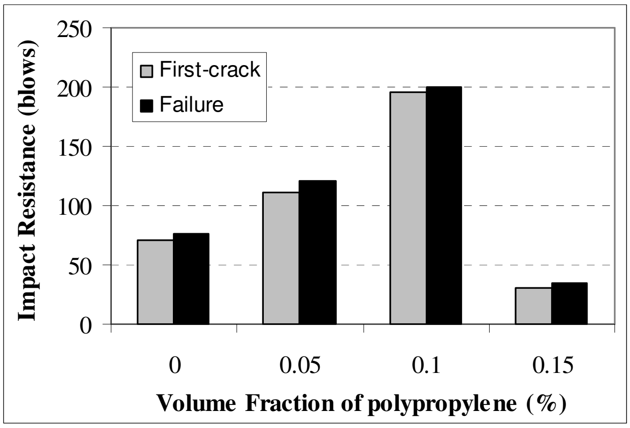

Figure 7: Effect of Polypropylene Fiber Addition on the Impact Resistance of SCC;

3.3 Discussion

Based on fresh state test results, it was clear that the addition of Polypropylene fibers results in deterioration of fresh properties of SCC. It is clearly observed that the flowability (Slump Flow) and passing ability (J-Ring) of SCC decreases when the presence of polypropylene fiber increased. Whereas, the viscosity and segregation resistance increasing in accordance with the volume fraction of polypropylene fibers content. Based on the results of flowability, viscosity and passing ability tests, it can be assessed that with polypropylene fiber addition up to 0.10% by volume of concrete, the mix can still meet the requirement of flowability, viscosity and passing ability of SCC as stated in the EFNARC guidelines for SCC mixes. The deformability of SCC reduces with the presence of polypropylene fiber. This could be caused of more surface area that should be lubricated by the cement paste and water. In the same time, polypropylene fibers also reduce the potential energy that needed by the fresh concrete to be able to flow by its own weight due to the increase of friction between aggregates and the fibers in the mixes.

The hardened properties test results show that compressive, tensile strength, and impact resistance of concrete specimens increase with an increase of fiber content up to 0.10 percent of the volume fraction, and then tend to decrease after 0.15 percent of polypropylene fiber addition. This could be achieved, due to the fact that polypropylene fiber bridges microcracks of which growth can be controlled. This leads to a higher strength of the composite. When the fibers addition passes over 0.15 percent by concrete volume, the instability of the concrete specimens which was realized earlier in the fresh concrete tests could have probably lead to a decrease in concrete strength.

4. Conclusions

Based on the tests results of the fresh and hardened state of self-consolidating concrete added with polypropylene fiber, the following conclusions can be drawn:

1. In the fresh state of SCC, when the presence of polypropylene fiber increased it caused lower flowability (Slump Flow) and passing ability (J-Ring) of SCC mixes. On the other hand, the viscosity and the segregation ratio of the mixes increasing in accordance with the volume fraction of polypropylene fibers content.
2. The concrete mixes can still meet the requirement of flowability, viscosity and passing ability of SCC with polypropylene fiber addition up to 0.10 percent by volume of concrete.
3. The compressive strength of concrete specimens improved proportionally with the addition of polypropylene fiber up to 0.05 percent by concrete volume, and then tend to decrease after 0.10 percent of polypropylene addition.
4. The splitting tensile strength of concrete specimens also improved in accordance with the addition of polypropylene fiber up to 0.10 percent by concrete volume, and then tend to decrease after 0.15 percent of polypropylene addition.
5. Better impact resistances of hardened SCC specimens can be observed proportionally with the increased of fiber content up to 0.10 percent by concrete volume, and then the impact resistance tend to decrease after 0.15 percent of polypropylene addition.
6. According to the evaluation of fresh and hardened properties of SCC, it seems that polypropylene fibers allowed to be added into the concrete mixes up to 0.10 percent by concrete volume.

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5. References

1. ACBM, (2007), The Center for Advanced Cement Based Materials White Paper: Self-Consolidating Concrete, in D.A. Lange (ed.), Northwestern University: The Center of Advanced Cement Based Materials (ACBM).

2. ACI 237R-07, (2007), Self-Consolidating Concrete, American Concrete Institute, Michigan.

3. ASTM, (2009), ASTM C1621 / C1621M - 09b Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring, ASTM International.

4. Banthia, N., and Nandakumar, N., (2003), Crack Growth Resistance of Hybrid Fiber Reinforced Cement Composites, Cement & Concrete Composites 25, pp 3–9.

5. EFNARC, (2005), the European Guidelines for Self-Compacting Concrete: Specification Production and Use, European Federation for Specialist Construction Chemicals and Concrete Systems, Norfolk United Kingdom.

6. Hsie, M., Tua, C., and Song, P.S., (2008), Mechanical Properties of Polypropylene Hybrid Fiber-Reinforced Concrete, Materials Science and Engineering A 494, pp 153–157.

7. Hwang, S.D., Khayat, K.H., and Bonneau, O., (2006), Performance-Based Specifications of Self-Consolidating Concrete Used in Structural Applications, ACI Materials Journal, 103(2), pp: 121-129

8. NRMCA, (2004), CIP 37 - Self Consolidating Concrete (SCC), National Ready Mixed Concrete Association, Maryland.

9. Russell, H.G., (2008), ASTM Test Methods for Self-Consolidating Concrete, HPC Bridge Views, Issue 50, Federal Highway Administration and the National Concrete Bridge Council, http://www.hpcbridgeviews.org/i50/Article4.asp, accessed 4 June 2012.

10. Song, P.S., Wu, J.C., Hwang, S., and Sheu, B.C., (2005), Statistical Analysis of Impact Strength and Strength Reliability of Steel–Polypropylene Hybrid Fiber-Reinforced Concrete, Construction and Building Materials, 19, pp 1-9.

11. Su, N., Hsu, K.C., and Chai, H.W., (2001), A Simple Mix Design Method for Self-Compacting Concrete, Cement and Concrete Research, 31, pp 1799-1807.